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H. E. Lambert, N. J. Alvares

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THE PEPCON DISASTER – CAUSATIVE FACTORS AND POTENTIAL PREVENTIVE AND MITIGATIVE MEASURES

Lambert, H.E.[1], Alvares, N. J.[2]

[1] Lawrence Livermore National Laboratory, Mail Stop L195, P.O.Box 808, Livermore, California 94550. USA
[2] Fire Science Applications, 751 Laurel Street, PMB 431, San Carlos, California 94070. USA

ABSTRACT

On May 4, 1988, the PEPCON plant experienced three major and several smaller explosions that caused over $70 million in property damage and caused two deaths. The PEPCON plant produced Ammonium Perchlorate (AP), a major ingredient for rocket fuel. The PEPCON plant and the nearby Kidd Marshmallow plant were totally destroyed by the detonations. The initiating event for the explosions was a fire that originated in the Batch Dryer Building and spread to adjacent storage. Several factors combined to cause the AP in the major storage fields to detonate, the most important being lack of adequate separation between storage units. Welding and flame cutting procedure with poor fire watch protocol was the prime candidate for fire ignition. There were no automatic fire suppression systems at the plant. Buildings including the Batch Dryer Building were made of combustible building material (fiberglass). There was poor housekeeping and no control of AP dust generation. AP was stored in combustible polyethylene drums, aluminum tote bins, 30-gallon steel storage drums and fiber reinforced tote bags. There were high-density storage practices. In addition, a contributing factor to the rapid fire-spread was that the wind that day was blowing directly from the batch dryer building to the storage areas. This paper claims that if codes, standards, and well-known hazard identification safety techniques were implemented at PEPCON, then the disaster would have been averted. A limited scope probabilistic risk assessment was conducted to establish the effectiveness of various preventive and mitigative features that could have been deployed to avert the disaster. The major hazard at the PEPCON site was fire and explosion involving the processing, production and storage of AP, which was then and is currently stored as a class 4 oxidizer. Since minute quantities of contamination can cause AP to be detonable by shock, there has been an ongoing debate concerning its reclassification to a class-A explosive.

INTRODUCTION AND BACKGROUND

This paper describes an analysis of conditions that contributed to the ignition and propagation of a fire that initiated several explosions in a plant that manufactured Ammonium Perchlorate (AP). The explosions occurred in 1988 at Henderson Nevada, a suburb of Las Vegas, Nevada, USA. Two of the explosions were the equivalent of more than 2 kilotons of TNT, which registered at 3.0 and 3.5 on the Richter scale at Caltech University in California. These explosions caused over 70 million dollars in damage to the surrounding industrial facilities and residences, death of two employees of the plant where the explosion occurred and injury to almost 400 people including plant employees, emergency personnel and adjacent residents. The fire grew to unmanageable size because code specified safety countermeasures were not in place. These countermeasures were mandated by both government and industrial agencies, but were not implemented because of production demand pressures. Moreover, scientific knowledge of the danger of AP and local experience during plant operations gave fair warning of the risk.

Properties of Ammonium Perchlorate

AP is a white or colorless odorless crystalline material. The major market for AP is as the oxidizer for solid phase rocket fuel. However, it has many other uses including; a component for explosives and fire works, the oxidizer for air bag propellants, components of adhesives; engraving agents, reagents, animal feed and various oxygen generating devices.

Ammonium Perchlorate (AP) (NH_4ClO_4) is designated in the U. S. National Fire Protection Association (NFPA) code 43 (1980) “ Code for the Storage of Liquid and Solid Oxidizers” [1] as a class 4 Oxidizer if the particle size is greater than 15 microns. The characteristics of Class 4 oxidizers are that they:

- Can explode when in contact with certain contaminants
- Can explode if exposed to slight heat, shock or friction
- Will increase the burning rate of combustibles
- Can cause combustibles to ignite spontaneously

According to the Occupational Safety and Health Administration (OSHA) of the U. S. Department of Labor [2], AP is stable in pure form at normal temperatures, and the threshold of decomposition is T>150º C, where the decomposition products are Chlorine, Hydrogen Chloride, and Nitrogen Oxides. Moreover, it is powerful oxide and can be explosive when contaminated with organic materials. Without contamination, it can be as sensitive to shock as a typical class-A explosive, and it may explode when involved in fire. The Pacific Engineering Production plant Pepcon safety rules [3] prior to the explosions stated that “Chlorates and Perchlorates, themselves, will not burn, but when Mixed with wood, paper, cloth, or and other organic matter, a highly flammable mixture is produced”. Kerr McGee Chemical corporation, another major AP producer, informed in a product bulletin [4] that AP is stable below 65.5° C but decomposes exothermically at 275°- and 470°- C respectively. This bulletin also indicates that pure AP will deflagrate at 349° C.

Batch Dryer Building

The AP involved in this explosion was being produced at Pepcon by a batch process that included combining electrolytically produced sodium perchlorate and ammonium chloride. The resulting AP was blended to customer specifications in several stages involving blending, evaporative drying, and kiln drying using a steam heated batch dryer. The dryer was located in a dual use building situated in the southwestern quadrant of the facility. The product size range was from 90 microns to 400 microns with most storage inventory averaging 200 microns.

AP Storage Practices at PEPCON

A variety of AP inventory containment options were used at Pepcon for bulk storage of product in line for final blending and for final shipment. These included; Aluminum bins of capacity of 5000 lbs (2268 kg), polyethylene lined steel drums of capacity of 250 lbs (113 kg) and bulk storage bags made of fiber reinforced polypropylene of capacity of 2400 lbs (1134 kg). The bins and bulk storage bags were also equipped with plastic containers for desiccants. In addition, over 10,000 drums made of high- density polyethylene with a capacity of 550 lbs (250 kg) were stored at various locations around the site. Generally, these drums contained product slated for intermediate procedures and blending. All the containers were composed of, or contain oxidizable materials. In addition, the majority of pavement for roadways and bulk storage fields was asphalt of which 25% is petroleum base material. The total inventory of AP at Pepcon at the time of the explosion was over 8.500,000 lbs (3,860,000 kg) distributed as shown in Fig. 1.

Figure 1. Aerial photograph of plant prior to explosions and fire.

Pepcon was obviously aware of the fire risk of AP and production engineers were probably cognizant of the potential for explosion of bulk quantities of AP from past experience and transportation regulations. [5]. Moreover, experience of ignitions of AP sensitized organics at the Pepcon plant gave fair warning that they were working dangerously close to the safety limits of some process procedures. Nevertheless they pioneered the use of Poly drums for convenience and for corrosion control knowing that the combination of organic materials with oxidizers was unwise. Indeed, simple comparison of the explosion energy of AP alone and AP in combination with the mass of polyethylene of a poly drum is astounding especially considering the ignition sensitivity enhancement provided by the combination. Thermodynamic evaluation of the internal energy and entropy of explosion for pure AP and AP in stoichiometric combination with polyethylene or asphalt show that the explosive strength, referenced to TNT is 0.5 and 1.5 times TNT respectively [6]. Clearly, the mass ratio for polyethylene drums and the AP content was oxidizer rich and the consequent energy release less than the stoichiometric ratio. This is consistent with independent analysis based on close-in structural deformation, which suggested a TNT air blast equivalence factor of 0.333, relative to the total inventory of AP on site [7]. The results of these explosions are shown in Fig. 2 and 3.

Figure 2. Aerial photograph of plant post the explosions and fire.

Figure 3. Aerial photograph of fire and explosion damage to process buildings around the batch dryer building.

When preparing AP for different customers, the practice at Pepcon was to load the dryer and monitor the temperature at unspecified intervals. In between checking the temperature, the dryer was left unattended for as long as 60 minutes [8]. Loading and unloading the dryer created much dust that deposited on walls and layered on horizontal surfaces of the structure. Housekeeping was casual and only performed well when inspections were scheduled. Dust along with dirt from the floor was swept and collected in poly drums for reprocessing [9]. Previous fire incidents in the batch dryer building were initiated by various causes including; belt and break friction, electrical sparks, undefined ignition of insulation on the dryer, overheated electrical motors and welding or flame cutting sparks. Each of these fires either burned out or were extinguished by water. The prime candidate for fire initiation on the day of the explosions was from welding or flame cutting sparks. Most of the process buildings on the site were constructed with steel framework to which fiberglass panels were attached as siding and roof structure, The welding and flame cutting operation was being done in close to the batch drying facility to repair damage caused by high winds.

The fire that initiated these explosions was first observed in the building housing the steam heated batch dryer by a workman in an adjacent building. Most of the employees were breaking for lunch, consequently (and perhaps luckily) only a few workmen were in the area of the fire, however, they attempted to attack the fire using standpipe water hoses. Unfortunately, when a second hose stream was deployed, the water pressure decreased to an ineffectual flow. The fire grew to involve AP stored adjacent to the building resulting in a small explosion which alerted all the employees of the plant and motivated them to prudently evacuate. (There was no general alarm or plant audible announcement system at the facility. “Radios were available among supervisors”. Plant personnel were advised to evacuate the premises if they observed a fire larger than an “incipient” fire. However, there was no evacuation plan).

Regulations and codes in force at the time of this explosion mandated that facilities of combustible construction that store or process Class 4 oxidizers or explosives required automatic fire detection and deluge sprinkler protection. In addition, each facility was required to have an emergency plan and periodic training exercises conducted in cooperation with local emergency organizations [10,11,12]. At Pepcon, there was none of the above. In fact the plant manager in charge of safety testified that he did not recall any specific requirements with respect to storage and handling of AP. The only fire alarm system at the plant was installed in the administration building and a warehouse used for equipment assembly.

The Pepcon plant had been one of two major suppliers of AP to the U. S. military/industrial complex since the early 1950’s. During that period, they experienced uneventful operation. Moreover, it can be assumed that they became comfortable with the operation and were complacent about the potential risk of their processes and storage practices. Had they applied risk analysis procedures developed by the nuclear and aerospace industries, the magnitude of risk in their production operations would have been exposed and practical and available methods to substantially mitigate the risk would have been obvious.

Shortly after the explosions, we were asked by counsel representing the industries and individuals that suffered loss to analyze the conditions leading to the initiation and spread of the fire in the process building housing the batch dryer. We were also tasked to develop a methodology that would have prevented the fire from growing beyond manageable size.

PROBABILISTIC RISK ASSESSMENT

The first step of the risk assessment was to identify the previous incidents that occurred at PEPCON prior to the accident and to assess the adequacy of the safety program that PEPCON employed.

The second step was to identify the appropriate hazard evaluation procedures to conduct the risk assessment. A reference document that was used at the time that the study was conducted is Guidelines for Hazard Evaluation Procedures, ref [13]. The procedures used in the risk assessment included (1) Process/System Checklists (2) Interaction Matrix, (3) Fault Tree Analysis and (4) Event Tree Analysis. Advantages to Hazard Evaluation Techniques are that they are (1) systematic, (2) numerous possibilities are considered, (3) concise graphical display of the analysis, (4) allow for assessment of design alternatives and (5) consider worst-case scenarios.

The use of event trees and fault trees in probabilistic risk assessment is discussed in [17] and [18].

The defense in depth measures considered to control and mitigate fire and explosion hazards are:

Reduce the initiating event frequency

Fires can be eliminated or controlled by limiting or controlling fuel, oxidant, and ignition sources through measures such as (1) quality assurance, (2) house keeping (3) electrical/mechanical design, (4) process inerting such nitrogen or carbon dioxide, (5) process control, e.g., interlocks, (6) operating procedures, (7) maintenance procedures and (8) AP dust removal systems.

Reduce the opportunity for fire growth, spread or propagation or secondary explosions

These mitigative measures include (1) fire detection systems (2) fire suppression systems (active), (3) manual fire suppression by personnel on site and the local fire department (active) (4) fire barriers, partitions, barricades (passive).

Reduce consequences

Reduce consequences by measures that include (1) increase distance between buildings (2) decrease the amount of AP in each process or storage area (3) evacuation procedures (4) locate plant in isolated area.

The third step was to construct event trees and fault trees.

Event Trees

Event trees were used for defining accident scenarios. The event tree is an inductive logic tree branching left to right with nodal decision points (yes or no). Undesirable consequences generally branch downward. Fig. 4 shows an event tree that represents the original case (without any added features.) The first heading shows the initiating event considered and its frequency. Failure probabilities (those events that branch downward) were assigned on the basis of actual operating experience. Pepcon had three batch house fires in seven years. Two fires were extinguished and third one on May 1988 was not. The frequency of batch house fires is estimated to be 1/7 per year. The probability of unsuccessful extinguishment is estimated to be 1/3.

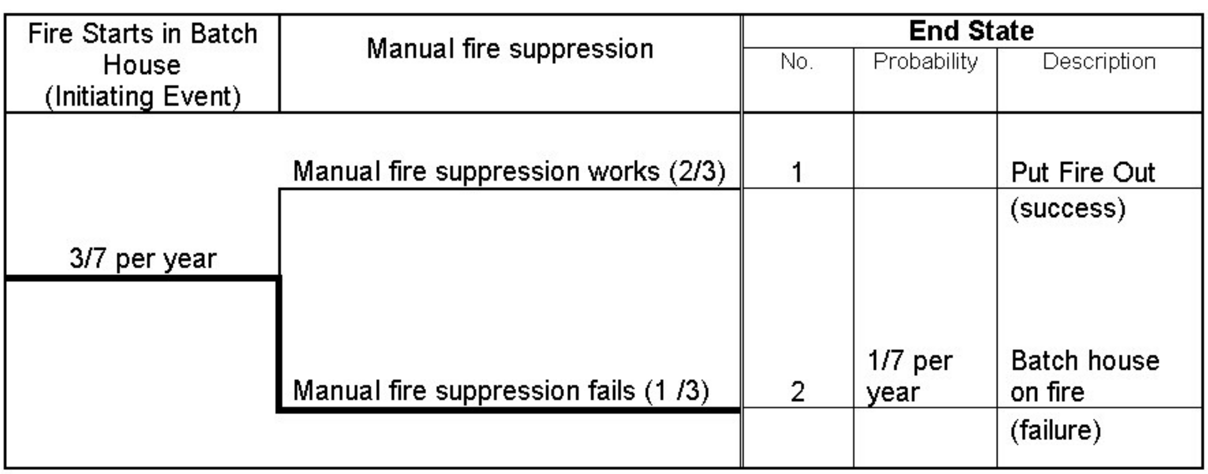

Figure 4. Event Tree Fire in Batch House (As plant existed May 4, 1988) Original Case

The study recommended the inclusion of trained personnel that know how to manually extinguish a fire and conduct a fire watch in the event welding or hot work is occurring. The study recommended the use of hose system as the first line of defense in extinguishing a fire. In addition, the inclusion of an automatic fire suppression system was recommended. (The details of this system are described later.) The event tree with all the proposed preventive and mitigative features are shown in Fig. 5. Fault trees were constructed and probabilistically evaluated to estimate failure probabilities for the manual fire suppression system and automatic deluge system.

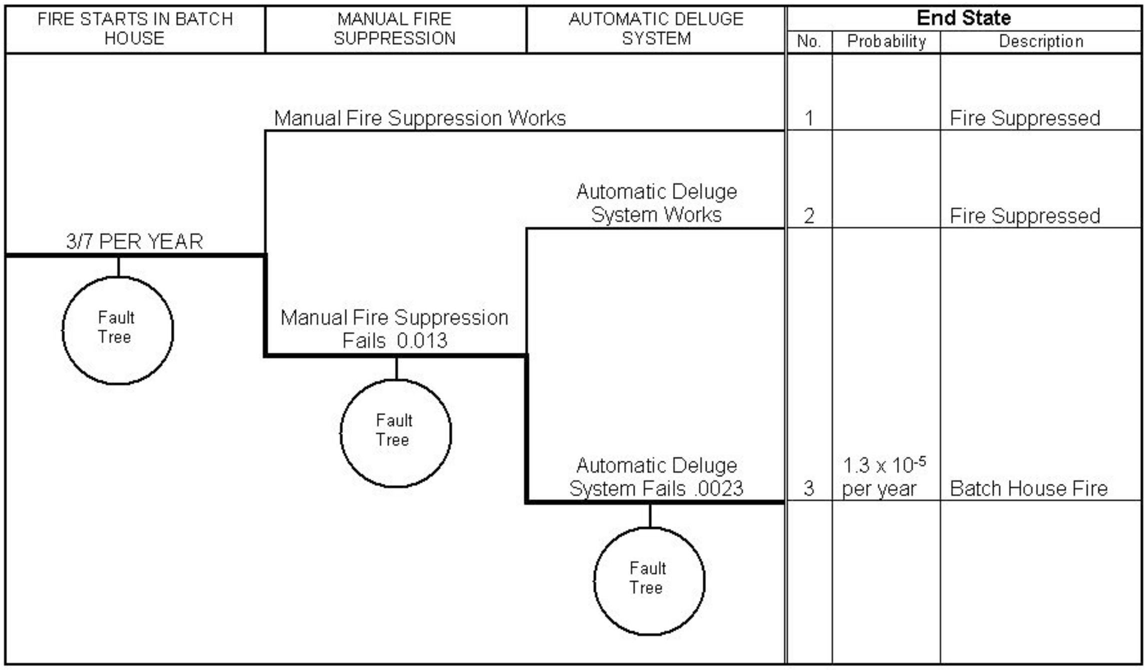

Figure 5. Event Tree Fire in Batch House Recommended System

Fault Trees

A fault tree is a deductive logic model. The fault tree starts with a defined top event, uses standard and or gates, is developed to the limit of resolution, called basic events. Basic Events include (1) equipment failure, (2) human error and (3) environmental conditions. A fault tree in Fig. 6 was used to generate the combinations of fuel sources, oxidizers and ignition sources. This fault tree is similar in scope to an interaction matrix. The study identified 7 possible fuel sources, 4 possible oxidizers and 13 possible ignition sources. There are a total of 364 combinations of triple events called min cut sets. The authors judge that the most likely ignition source for the batch house fire is incandescent particles from welding and/or flame cutting. An alternate ignition candidate is judged to be heat from the dryer that on previous occasions has ignited the dryer insulation made from cheesecloth.

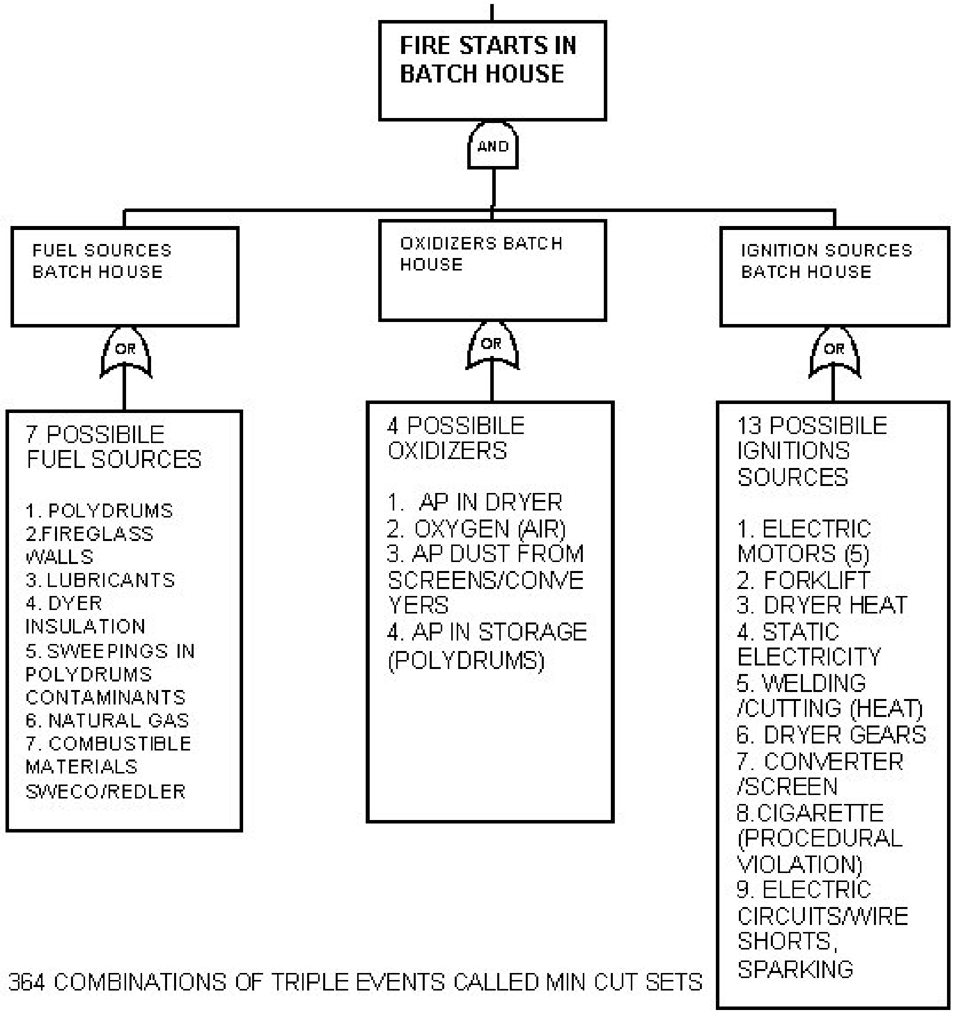

Figure 6. Fault Tree for Fuel/Oxidizer/Ignition Source

Water Deluge System Design and Testing

The study recommended the inclusion of water deluge system shown in Fig.7.

The features are described below.

1. A dedicated fire water supply system with a fire water tank and four pumps, two electric and two diesel driven
2. Automatic activation with at least two fire detectors and an automatic deluge valve
3. Manual Activation with a manual backup valve, a fire alarm to alert the operators and manual start of the pumps
4. A hose system that is used for manual fire suppression – the first line of defense for fire extinguishment

The following inspection frequencies for the proposed deluge system were recommended based upon NFPA standards:

1. Check fire water level once a month
2. Every six months test fire water pumps, fire alarm, fire detector and deluge valve

3. Once every year, full test of deluge system

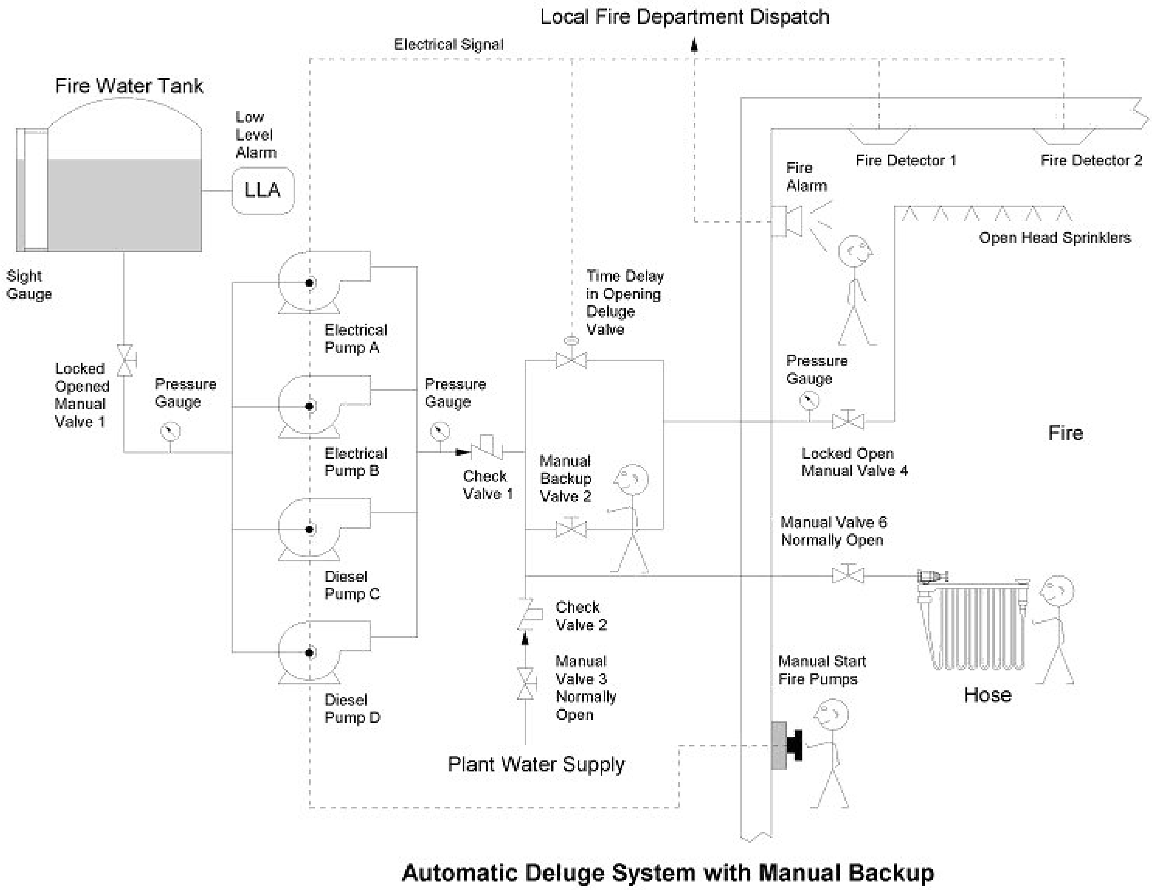

Figure 7. Automatic Deluge System with Manual Backup

The top level fault tree for manual extinguishment is shown in Fig. 8. The fifth step of the process was to quantify the fault trees and apply applicable probability data. The probability data that was used include Swain and Guttmann, NUREG 1278 [14], Interim Reliability Evaluation Program, NUREG 2728 [15] and RADC, Non-electronic Reliability Notebook [16].

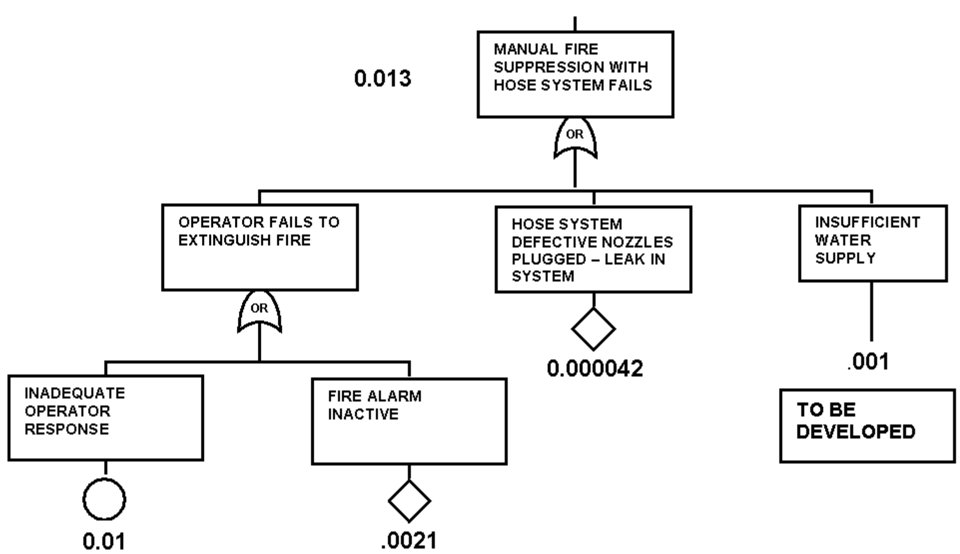

Figure 8 - Top Level Fault Tree For Manual Fire Suppression

The top event probability (probability of failure for manual extinguishment) is calculated to be 0.013. The fault tree for the automatic deluge system is shown in Fig. 9. This fault tree shows the dominant causes of failure that include failure of the manual locked open manual valves, check valve failure and inadequate water supply in the fire tank. Failure of the pumps and signal actuation system did not dominate probabilistically due to redundancy. The top event probability for failure of automatic deluge system given a fire is calculated to be 0.0023. From Fig. 5, the total frequency of a batch house fire with recommended measures employed is:

$$\frac{3}{7}0.013 \cdot 0.0023 = 1.3 \cdot 10^{-5} \text{ per year}$$

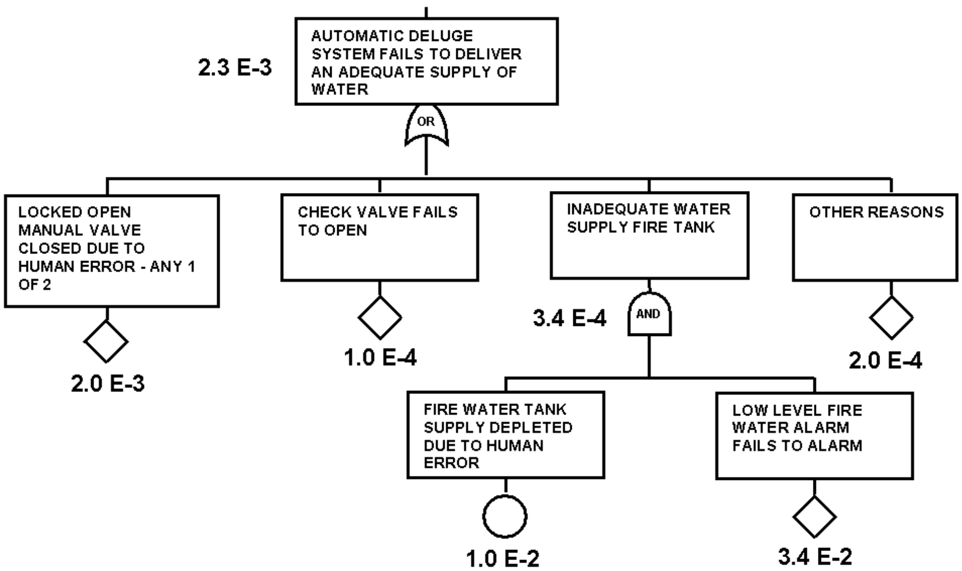

Figure 9. Top Level Fault Tree For Automatic Deluge System

CONCLUSIONS

A measure of risk reduction is the original frequency of batch house fire divided by the frequency of batch fire with measures employed,

i.e., $\frac{1/7}{1.3 \cdot 10^{-5}} \approx 10{,}800$

Based upon the risk assessment and good engineering practices, the authors felt that the following procedures and systems should have been incorporated at PEPCON:

1. Better fire watch training
2. Better housekeeping
3. Ventilation system
4. Elimination of fuel sources
5. Sprinkler/deluge systems
6. Elimination of combustible building products

7. Alarm and fire sensing systems
8. Storage spacing and separation
9. Evacuation procedures
10. Standpipes that use gravity flow

These procedures would cost more initially, but the risk analysis that should precede their implementation would clearly show the cost benefit of the fire protection countermeasures and training.

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